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ORIGINAL PROGRAM DIRECTOR: **Dr. Ken Chong**

Integrated Design/Construction Research Program for Infrastructure Rehabilitation

Close-out Report

Principal Investigator:

Dr. Jorge A. Vanegas

The Fred and Teresa Estrada Professor
College of Engineering (CoE)

Associate Professor and Group Leader
Construction Engineering and Management Program (CEM)
School of Civil and Environmental Engineering (CEE)
College of Engineering (CoE)

and

Co-Director Construction Resources Center (CRC)
College of Architecture (CoA)

Georgia Institute of Technology
Atlanta, Georgia 30332-0355
U.S.A.

Tel.: (404) 894-9881 • Fax: (404) 894-5418
Email: jvanegas@ce.gatech.edu

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Integrated Design/Construction Research Program for Infrastructure Rehabilitation

Close-out Report

The National Science Foundation (NSF) National Young Investigator Award (NYI), NSF Grant No. MSS 9396314, funded an “*Integrated Design/Construction Research Program for Infrastructure Rehabilitation.*” This is the program close-out report.

Goals and Objectives, Activities, and Findings

Goals and Objectives

[This section reiterates the goals and objectives of the research and teaching program under this award.]

Research Plan

The original primary objective of the research program under this award was to develop a conceptual framework for a new and innovative approach to infrastructure rehabilitation problems that explicitly and formally integrated design and construction throughout the design and construction phases of a project; from scope definition, conceptual and schematic design, and design development, to construction planning and execution.

The research program was designed around two inter-related and complementary thrusts:

- the analysis, assessment and planning of infrastructure rehabilitation projects; and
- the implementation and execution of infrastructure rehabilitation projects.

The overall research plan was designed to be flexible enough to accommodate a wide range of research approaches; from focused single-discipline individual stand-alone projects, to extensive multi-phase inter-disciplinary efforts.

As a result of the matching funds provided by the GE Fund, of several other research initiatives related to the research program under this award, and of findings as the program evolved, the scope and objective of the research program changed and expanded to address four research questions.

- First, could the conceptual framework expand from just an explicit and formal approach to integrate design and construction in infrastructure rehabilitation projects, to a more comprehensive systems-based approach for increasing the effectiveness and efficiency of Facilities and Civil Infrastructure Systems (F&CIS) projects, throughout their complete life cycle (i.e., from the initial project driver, through planning, design, construction, and operation, to the end-of-service life decision)?
- Second, could the conceptual framework be anchored within the context of sustainable development and technology, to reduce or minimize the problems of natural resource depletion and degradation, waste generation and accumulation, and environmental impact and degradation caused by current approaches to the delivery and use of F&CIS, from both a product and a process perspectives?

- Third, could the conceptual framework be anchored within the context of quality, productivity improvement, enhanced project performance, and lean thinking principles and concepts, to increase the overall value of the project to an owner, and to achieve a better definition and flow of the value stream in the execution of the project, a reduction in the cycle time of the project, and better management of the construction production process?
- Finally, could the conceptual framework include a cohesive and integrated map for the development and implementation of an advanced technological infrastructure required for effective and efficient management of knowledge, experience, data, and information, at both an enterprises and a project levels?

Teaching Plan

The original primary objective of the teaching program under this award was to develop a comprehensive teaching plan to strengthen and enhance undergraduate and graduate education, and to provide a mechanism for technology transfer to industry. The teaching program was designed around three inter-related and complementary thrusts:

- curriculum development, which focused on strengthening both the undergraduate and the graduate curricula in Construction Engineering and Management within Civil and Environmental Engineering;
- teaching innovation, which focused on strengthening the skills and abilities of students to analyze, visualize, synthesize and model infrastructure rehabilitation problems, and to design, develop, test, and optimize alternative solutions; and
- technology transfer, which focused on advancing the profession by contributing to expand its underlying technological and knowledge base.

As a result of the matching funds provided by the GE Fund, of several other research initiatives related to the research program under this award, and of findings as the program evolved, the scope and objective of the teaching program expanded to address education in the area of sustainability at a global engineering level, at the graduate and undergraduate levels in Civil and Environmental Engineering and specifically in Construction Engineering and Management, and for industry practitioners.

Activities

[This section reiterates the principal activities within the research and teaching program under this award.]

Research Activities

A major on-going activity within the research program under this award was a comprehensive literature review to establish the global states of knowledge in rehabilitation of civil infrastructure systems; best practices for effective and efficient planning, design, procurement, construction, commissioning and start-up, operations, maintenance, and end-of-service life options of facilities and civil infrastructure systems projects; design/construction integration, design-build, and constructability; strategies, mechanisms, and technologies for management of lessons learned, knowledge, experience, information, and data; sustainable development and technology; quality, productivity improvement, enhanced project performance, and lean thinking. Several undergraduate and graduate students assisted in conducting this literature review. They collected, classified, organized and stored specific data and information from a

wide range of sources, which helped specific research activities. [with Roberto Eljaiek, Abdul Khan, Rachelle Jansen (at Purdue University), and Adlin Blanco, Sergio Botero, Heidi Martinez, Mario Penovi, Fernando Sarria, Hugo Vargas, Kobi Wu (at Georgia Tech)]

The results of this review provided a solid foundation for the general and specific research activities described next.

General Research Activities.– In addition, general research activities of the research program under this award included:

- the definition of the context for F&CIS projects from an enterprise perspective, including the (a) identification of the major elements and trends in the enterprise, (b) the understanding of triggers, modes, and barriers to change, and (c) definition of a technological infrastructure for the enterprise
- the definition of the context for F&CIS projects from a project perspective, including the (a) identification of the major elements in a project, (b) definition of an integrated model of the total life cycle of a project, (c) understanding of the relationships between knowledge, experience, information, and data, and influence and risks, (d) development of a paradigm shift for defining performance, and (e) definition of a technological infrastructure for the project
- the definition of the context for collaboration within the A/E/C industry for innovation and new developments in materials, equipment, and technologies for F&CIS projects
- the development of a model for achieving sustainability in the built environment, including (a) a sustainable system approach to development in the A/E/C industry, and (b) a sustainable approach to the life cycle of F&CIS projects from a product and process perspectives
- the development of a taxonomy for F&CIS projects by industry sector and by project type
- the development of a methodology for developing integrated project definition packages, including the (a) identification and definition of the performance parameters for F&CIS projects, (b) identification and definition of the external and internal influences on performance for F&CIS projects, (c) identification and definition of the principal stakeholder perspectives in F&CIS projects, and (d) the process that needs to be followed
- the development of models for (a) an enhanced integrated project definition process, (b) an enhanced design process, and (c) an enhanced construction process
- development of a dynamic mechanism to acquire, process, store, retrieve/disseminate, and apply internal lessons learned and external best practices from, and for, any stage of the life cycle of a F&CIS project, as the basis of an infrastructure for implementing a learning organization approach within organizations involved in F&CIS projects, e.g., owners, design firms, construction firms

Specific Research Activities.– Other specific activities related directly and indirectly to the research program under this award included, in no particular order:

- development of a multi-objective optimization model for sewer rehabilitation, which identifies the sections or lengths that need to be rehabilitated in a sewer system, if size changes are needed, and the rehabilitation method(s) to use; model objectives include minimization of total life-cycle costs, minimization of global consequences of failure, maximization of overall hydraulic performance, and minimization of disruptions [with Santiago Reyna; doctoral student at Purdue University; Ph.D. 1993]

- development of a decision support system methodology to improve the effectiveness of decision-making in semi-structured tasks, specifically for establishing cost control strategies [with Makarand Hastak; doctoral student at Purdue University; Ph.D. 1994]
- development of a theoretical framework for the development, acquisition, storage, retrieval and manipulation of constructability lessons learned using multimedia computer technologies, as a starting point for the development of a constructability knowledge base [with Bob Patty; doctoral student at Purdue University; Ph.D. 1994; with funding support from the Indiana Department of Transportation Joint Highway Research Project]
- development of a taxonomy of knowledge requirements for construction executives of general construction and construction management enterprises [with Robin Goodman; doctoral student at Georgia Tech; Ph.D. 1998]
- development of a hybrid process for prioritizing facility-related problems and allocating resources to solve those problems, based on the objective of increasing facility sustainability while meeting other goals and constraints faced by facility decision makers enterprises [with Annie Pearce; doctoral student at Georgia Tech; Ph.D. 1999]
- development of a model of organizational change for federal agencies, along with a model for identifying and prioritizing better maintenance alternatives for federal facilities, specifically the U.S. Forest Service enterprises [with Anna Jones-Crabtree; senior engineer with the Forest Service; doctoral student at Georgia Tech; target completion Ph.D. 2000]
- development of an objective setting methodology for planning construction projects to achieve sustainable development from an owner's point of view [with Francisco Maldonado-Fortunet; assistant professor at the University of Puerto Rico-Mayagüez; doctoral student at Georgia Tech; target completion Ph.D. 2000]
- development of a methodology for prediction of construction disputes in change issues [with Kyoochul Shin; doctoral student at Georgia Tech; target completion Ph.D. 2000]
- development of a model for integrating sustainability and lean construction principles in affordable housing developments [with Ing. José Loría-Arcila; director of the Construction Engineering and Management Program at the University of Yucatan in Merida, Mexico; doctoral student at Georgia Tech; target completion Ph.D. 2001]
- development of an integrated project definition model for the A/E/C industry [with Stephen Mulva; doctoral student at Georgia Tech; target completion Ph.D. 2001]
- development of innovative practices for cost effective engineering [with a team of research assistants at Georgia Tech – Dr. Makarand Hastak (Post-Doctoral Fellow), Annie Pearce and Francisco Maldonado-Fortunet (Doctoral Candidates), and Banjo Babatunde, Lina Barón, Oscar Herrera, Andrés Pinzón, and Jennifer Werner (graduate students); with funding support from the Construction Industry Institute (CII) through Research Team 121]
- development of a survey framework and methodology for collecting data and information required to develop planning, design, construction, and operation strategies and guidelines for a sustainable orphanage [with a team of students at Georgia Tech – Annie Pearce (doctoral student), Darren Pence (graduate student), and David Kowalsky and Joseph D. Harder (undergraduate students); with

funding support from the NSF Research Experience for Undergraduate (REU) Program through two supplements to this NYI award]

- establishment of an advanced computer laboratory for environmentally conscious design and construction that provides design, visualization, modeling, prototyping, simulation, multimedia, and other computational capabilities and functionalities to enable collaborative based research activities utilizing shared video, as support to the research and development of strategies, methodologies and tools/techniques for environmentally conscious design and construction of F&CIS projects, and for environmentally conscious building technologies, systems, products and materials [with an interdisciplinary team of faculty at Georgia Tech; with funding support from the Georgia Research Alliance]
- establishment of a collaborative research program in affordable sustainable housing between the Construction Engineering and Management Graduate Programs at Georgia Tech and at the Universidad Autónoma de Yucatán, Merida, Mexico [with funding support from the NSF-CONACyT Collaborative Research Opportunities (CRO) Program with Mexico through a NSF supplement to this NYI award, and additional matching funds provided by CONACyT]
- contributed to the establishment of a funded program for applied research, technical assistance, and outreach in Sustainable Facilities and Infrastructure [in collaboration with Dr. Annie Pearce, Director SFI Program, the Safety, Health, & Environmental Technology Division (SHETD) of the Electro-Optics, Environment, & Materials Laboratory (EOEML) of the Georgia Tech Research Institute (GTRI)]
- establishment of a Pan American initiative in affordable sustainable housing policy, development and technology at Georgia Tech [with funding support from the Alfredo and Teresa Estrada Professorship in the College of Engineering at Georgia Tech]

Teaching Activities

A major on-going activity within the teaching program under this award was a literature review to establish the global states of knowledge in the use of state-of-the-art computer technologies in classroom and laboratory instruction; problem-based, case-based and collaborative learning and reasoning; creativity; problem-solving; design; curriculum development; and existing continuing education modules on practices for effective construction project management. Several undergraduate and graduate students at Georgia Tech assisted in conducting this literature review. They collected, classified, organized and stored specific data and information from a wide range of sources, which helped specific research activities. [with Adlin Blanco, Sergio Botero, Heidi Martinez, Mario Penovi, Fernando Sarria, Hugo Vargas, Kobi Wu]

The results of this review provided a solid foundation for the general and specific teaching activities described next.

General Teaching Activities.— The major general activities of the teaching program under this award included:

- upgrade and improvement of the course content of existing courses in both the undergraduate and the graduate curricula in Construction Engineering and Management within the School of Civil and Environmental Engineering at Georgia Tech
- development of innovative educational approaches, methods, and tools, and new delivery systems for both classroom and laboratory instruction that generate enthusiasm for learning, are flexible, are

intellectually stimulating, foster creativity and innovation, strengthen the integrative skills of students for the analysis, synthesis, and contextual understanding of engineering problems, satisfy academic and professional requirements, and emphasize the design and problem-solving nature of engineering practice, and increase the use of state-of-the-art computer technologies in classroom and laboratory instruction

- development and delivery of workshops and focused continuing education courses

Specific Teaching Activities.— Other specific activities related directly and indirectly to the teaching program under this award included, in no particular order:

- management of a five-year multidisciplinary effort for the development and implementation of a curriculum in sustainable development and technology to be deployed across different engineering schools, and support to various educational, dissemination and informational exchange initiatives, both within and outside the Institute; this project served as one of the original cornerstones for Georgia Tech's current institutional commitment to sustainability through its education, research, and outreach programs, and also through its campus master plan and physical plant [with an multidisciplinary team of faculty at Georgia Tech; with funding support from the GE Fund, which provided the matching funds for the NSF/NYI award, and from the NSF Course and Curriculum Development (CCD) Program – Grant #DUE-9354483]
- active involvement and participation in the activities of the EduTech Institute at Georgia Tech, a group that pioneered new, cognition-driven applications of multimedia computer technology to enhance (a) teaching and learning, (b) understanding of a complex knowledge domains in highly interdisciplinary environments, and (c) creativity in finding solutions through a carefully planned and designed educational environment, solidly based on cognitive science principles [with an multidisciplinary team of faculty at Georgia Tech; with funding support from the Woodruff Foundation]
- active involvement and participation in the development of an integrated multimedia support system for teaching sustainable development and technology using a problem-based, case-based and collaborative learning and reasoning approach, which served as the basis for the eventual development of CaMILE (Collaborative and Multimedia Interactive Learning Environment), a software support tool that facilitates and structures discussion among students (asynchronously and at diverse locations) as they are solving design problems, and allows students to comment on others' notes, to explicitly identify the kind of comment being made (e.g., rebuttal, alternative, question), to access libraries of information (including a case library), and to annotate their comments with multimedia links, including links into a case base or network resources [with Dr. Mark Guzdial; College of Computing; Georgia Tech; with funding support from the EduTech Institute]
- training of four high school and middle school teachers during an eight-week summer session in research, in the use of educational multimedia technology, and in the application of new pedagogical approaches to the classroom through the development of educational modules and activities within the domains of infrastructure rehabilitation and sustainability [with teachers Gwendolyn White (McNair Senior High School, DeKalb County School System, Atlanta, GA), Barbara Woolfolk (Frederick Douglass High School, Atlanta Public School System, Atlanta, GA), Carol Turner (Five Forks Middle School, Gwinnett County School System, Lawrenceville, GA), and Roger Ivey (Lilburn Middle School, Gwinnett County School System, Lilburn, GA); with funding support from

the Georgia Industrial Fellowships for Teachers (GIFT) Program at Georgia Tech through two NSF supplements to this NYI award and two supplements to another related NSF award]

- active involvement and participation in an interdisciplinary effort for the development and implementation of a curriculum in infrastructure assessment, rehabilitation, and reconstruction [with an interdisciplinary team of CEE faculty at Georgia Tech – Dr. Glenn Rix, Dr. Lawrence Jacobs, Dr. Nelson Baker, Dr. Riyad Aboutaha, and Dr. Abdul Zureick; with funding support from the funding support from the NSF Combined Research/Curriculum Development (CRCD) Program – Grant #EEC-9420522]
- development and delivery of a course on “Advanced Tools and Techniques for Effective Project Management,” which provides students with a theoretical foundation for dealing with construction engineering and management issues in the implementation of infrastructure rehabilitation projects based on the results of research by the Construction Industry Institute (CII), and which was adapted and customized as a new undergraduate technical course elective, a new graduate technical course elective, and a continuing education module for general contractors [with in-kind support from CII, and funding support from the NSF Combined Research/Curriculum Development (CRCD) Program – Grant #EEC-9420522, from the Del E. Webb School of Construction, Arizona State University, Tempe, Arizona, through a visiting eminent scholar appointment, and from Siemens Energy & Automation, Inc., through Continuing Education at Georgia Tech]
- participation in the workshop on “Creativity in Engineering Education,” sponsored by the Engineering Foundation at Stanford University [with funding support from the Engineering Foundation through a scholarship to attend the workshop]
- development and delivery of “Project Alignment and Partnering Development and Maintenance Seminars,” for capital projects of a steel-producing industrial owner University [with funding support from U.S. Steel through Continuing Education at Georgia Tech]
- development and delivery of an educational module on “Constructability,” for the National Aeronautics and Space Administration (NASA) personnel involved in facility asset development and maintenance [with funding support from NASA as an invited course developer and instructor]
- development of a graduate course on “Analysis and Design of Construction Operations: A Framework, Strategies, and Tools for Productivity Improvement,” taught at a university in Colombia and at a university in Mexico [with funding support from the Departamento de Ingeniería Civil, Programa de Maestría en Construcción, Universidad de los Andes, Santafé de Bogotá, Colombia, and from Facultad de Ingeniería, Programa de Maestría en Construcción, Universidad Autónoma de Yucatán, Mérida, Mexico, through invited visiting scholar appointments]
- development of a graduate course on “Advanced Construction Project Planning and Scheduling,” taught as an invited visiting scholar at a university in Mexico [with funding support from Escuela de Ingeniería Civil y Administración, Programa de Maestría en Administración de la Construcción, Universidad Panamericana – Sede Guadalajara, Guadalajara, Mexico, through an invited visiting scholar appointment]
- contributed to the development and delivery of a continuing education modules on “Modularization in Industrial Construction,” and on “Implementing Constructability,” within the Construction Industry Institute (CII) Continuing Education Short Courses (CESC) series for professionals in the A/E/C industry, and deployed at (a) Continuing Education Services (CES) at The University of Texas at Austin; Austin, Texas; (b) Construction Industry Cooperative Alliance (CICA) at Clemson

University; Clemson, South Carolina; and (c) Alliance for Construction Excellence (ACE) at Arizona State University, Tempe, Arizona [with funding support from CII, CESC, CICA, and ACE as an invited course developer and instructor]

- development and delivery of a new technical course on “Environmentally Conscious Design and Construction,” a required graduate course focusing on an integrated life cycle approach to the delivery of facilities and civil infrastructure systems projects from an environmentally conscious perspective, which introduces students to a framework for integration, and basic concepts and principles of sustainable development, and exposes them to strategies and tools for environmentally conscious design and construction of facilities and civil infrastructure systems
- academic advisement, mentoring, and independent research supervision for a Hispanic undergraduate student [for Patricia Sepulveda; with funding support from the NASA Undergraduate Student Researchers Program]
- development of a comprehensive framework for research, including (a) development of a research prospectus, (b) development of research proposals, (c) management of a dissertation, and (d) advisor/student expectations
- preparation and delivery of multiple presentations on results from the research program under this award at technical conferences, symposia, workshops, and other special events in the U.S. and abroad, for both professional and student audiences

Findings

[This section summarizes the principal conclusions that have emerged from the activities within the program under this award.]

General Findings

The research program under this award has developed a comprehensive systems-based framework for increasing the effectiveness and efficiency of F&CIS projects throughout their complete life cycle, from the initial problem, need or opportunity that drives the project, through planning, design, procurement, construction, commissioning and start-up, operation, and maintenance, to an end-of-service life decision to demolish, deconstruct, decommission, rehabilitate, retrofit, recover, restore, replace, or remediate.

This framework includes a companion set of strategies, processes, models, and tools that can be customized, implemented, and used by public and private owner organizations, architectural and engineering design organizations, and construction organizations. Both the framework and the set of strategies, processes, models, and tools can be applied to (1) public and private projects in the various sectors of the construction industry (i.e., heavy/civil construction, industrial construction, building construction, residential construction, and land/real estate development); and (2) different types of projects (i.e., greenfield and brownfield development projects, rehabilitation projects, retrofit projects, disaster recovery projects, historical restoration and preservation projects, environmental remediation projects, and demolish, deconstruct, and decommission).

The framework has three important features.

- First, the framework is firmly anchored within the context of sustainable development and technology. The framework identifies critical “sustainability entry points” that will enable owners, designers, and constructors to proactively, formally, explicitly, and systematically incorporate

sustainability principles and concepts into the decision-making process at any phase of the life cycle of a project. The anticipated result is a reduction or minimization of the problems of natural resource depletion and degradation, waste generation and accumulation, and environmental impact and degradation caused by current approaches to the delivery and use of F&CIS.

- Second, the framework is firmly anchored within the context of quality, productivity improvement, and enhanced project performance. The set of strategies, processes, and tools contained in the framework will enable owners, designers, and constructors to proactively, formally, explicitly, and systematically incorporate lean thinking principles and concepts into the technical and management processes at any phase of the life cycle of a project. The anticipated results are an increase in the overall value of the project to the owner; a better definition and flow of the value stream in the execution of the project; a reduction in the cycle time of the project; better management of the construction production process; and overall elimination of waste.
- Third, the framework provides a cohesive and integrated map for the development and implementation of an advanced technological infrastructure required for effective and efficient management of construction enterprises and projects. This technological infrastructure includes computer-based technologies for enterprise-level and project-level management of knowledge, experience, data, and information, and also, advanced construction materials, equipment, and methods technologies used in F&CIS projects. The anticipated results are a more strategic and proactive approach to the development, implementation, and application of advanced technologies at an enterprise, project, and field levels.

Specific Major Findings

- Enterprises involved in F&CIS projects need to reconcile the effectiveness, efficiency, productivity, and profitability of their response to the global economy, their markets, and their clients (i.e., its external context), with their current organization (i.e., its internal context), which is defined by a set of basic infrastructures (i.e., physical, human, technological, technical, management, and administrative), and by a set of core assets and competencies (i.e., data/information and knowledge/experience, skills/abilities, and technological proficiency). In many cases this response is not as effective, efficient, productive, and profitable as it can be as a result of the increasing gap between the speed of change of the external context (exponential) compared to the speed of change of the internal context (linear).
- To close the gap between external context requirements and the internal context of their organization, enterprises are eliminating non-essential elements of their internal context, strengthening the essential ones, and outsourcing important, but non-essential elements of their infrastructures and competencies through strategic alliances and partnerships. These trends are forcing enterprises to understand better the triggers of change (i.e., flash or internal/proactive, crash or internal/reactive, splash or external/proactive, and crash or external/reactive); the modes of change (i.e., natural evolution with incremental or accelerated change, revolution, or punctuated evolution or managed controlled change); and the barriers to change.
- Enterprises require a special technological infrastructure to support its vision, mission, strategic plan, and business plans (as opposed to just project-oriented technologies).
- Effective and efficient planning and execution of F&CIS projects require a clear understanding of (a) the project originator (whether it is at an individual, functional unit, organizational unit, or enterprise levels); (b) the project genesis (a problem, a need, or an opportunity); (c) the project definition

package; (d) required/available resources (economic, financial, physical, human, intellectual, and technological); and (e) a clear idea of when the project starts and when it should finish.

- It is necessary that the roles and responsibilities of every organization and individual involved in the project be clearly defined, and that project stakeholders always see the project from a total integrated life cycle perspective, with seamless transitions across the planning, design, procurement, construction, commissioning and start-up, operations, maintenance, and end-of-service life decision phases. Understanding and management of overall group and team dynamics, and of the roles, styles, and behaviors of individuals in the project team is a special area that needs attention in a F&CIS project.
- It is critical to (a) understand the influence curve of decisions made throughout the life cycle of the project; (b) understand risk as a function of available data/information and knowledge/experience; (c) select the delivery system and contract type for the project as a function of risk analysis and distribution; and (d) to define project performance beyond the traditional paradigm of cost, time and quality.
- Projects require a special technological infrastructure to support specialized computing applications, communication, collaboration, and management of data/information and knowledge/experience.
- To further innovation and new developments, there is a need to increase the level of collaboration within the A/E/C industry among the organizations involved in the total life cycle of facilities, the organizations involved in the total life cycle of civil infrastructure systems, and the organizations involved in the total life cycle of technologies, systems, products, materials, and equipment used in F&CIS projects. Establishing mechanisms for collaboration (e.g., forums for exchange of ideas or technical developments) will create a push/pull relationship between any of these types of organizations.
- To achieve sustainability, the A/E/C industry requires significant changes in the way the industry currently approaches and delivers F&CIS projects, and also, in the way manufacturers and vendors supply the building technologies, systems, products and materials used in these projects.
- At an industry level, the prevalent unsustainable linear approach to F&CIS projects (from the extraction and use of primary renewable and non-renewable natural resources, and the production and use of energy, through processing and manufacturing processes, and the commercialization and transport of technologies, systems, products, and materials used in the delivery of projects, to their operation and maintenance throughout their service life, until an ultimate decision is made whether to rehabilitate, retrofit, dismantle, or decommission them), needs to shift toward a closed cyclical system for the industry, which is framed within a social/cultural, political, economic, technological, and ecological/environmental context, and gradually moves towards sustainability. This system must incorporate four additional elements, each a response to a specific sustainability challenge, as mechanisms to explicitly and systematically: (a) reconcile the delivery, operation, maintenance, and end-of-service-life decision of F&CIS projects, with the intra- and intergenerational satisfaction of human needs and aspirations; (b) incorporate sustainable strategies and technologies proactively within every element of the system, that promote the development, and enable the use, of environmentally conscious alternatives and substitutes to current resources and energy sources used in the delivery, operation, and maintenance of F&CIS projects, prevent or mitigate environmental impacts before any damage to the environment occurs, such as preservation, pollution prevention, avoidance, monitoring, assessment and control technologies, and correct environmental impacts

when some damage to the environment already has been done, such as remediation or restoration technologies; (c) promote recovery of selected resources and products actively within every element of the system, through direct reuse of reusable components, remanufacture of reusable elements, reprocessing of recycled materials, and monomer/raw material generation; and promote natural resource management actively during processing and manufacture, energy production and use, and extraction and use of primary resources, through the extraction of renewable natural resources from the biosphere in a way that ensures that the supply will always exceed the demand, and through monitoring and control of the extraction of non-renewable natural resources from the lithosphere to prevent their total depletion.

- At a project level, sustainability goals, concepts, principles, and guidelines need to be explicitly and systematically integrated in a project, at all stages of its life cycle, particularly the early funding allocation, planning and conceptual design phases. One way of achieving this goal is to develop a cohesive set of policies for implementation of sustainability at various key sustainability entry points: project characterization and project definition practices; project team building practices; planning, design, procurement, construction, and commissioning and start-up practices; operation and maintenance practices; and end-of-service life transitions.
- Proper characterization of a F&CIS project requires an in-depth understanding of its features, attributes, and characteristics by industry sector ((i.e., heavy/civil construction, industrial construction, building construction, residential construction, and land/real estate development), and by project type: (a) new greenfield, and brownfield facility development projects; (b) rehabilitation of deteriorated facilities to correct the effects of natural deterioration; (c) retrofit of existing facilities to modify, expand, and/or upgrade them; (d) emergency recovery projects to correct the effects of natural or human-caused disasters; (e) projects to restore/ preserve/protect existing facilities with historical or cultural value; (f) projects to correct environmental problems affecting, or caused by, existing facilities; and (g) decommissioning, deconstruction or demolition to dispose of existing facilities.
- A comprehensive integrated project definition packages for a F&CIS project, should include (a) identification and definition of the performance parameters for the project, (b) identification and definition of the external and internal influences on the performance of the project, (c) identification and definition of the perspective of the principal stakeholders in the project.
- There are twelve principal categories of short-term and long-term performance parameters for a F&CIS project: (a) the physical and nonphysical contextual compatibility and response of the project, including compliance with all applicable laws, codes, and regulations, and response to the specific requirements of site conditions and local area context and practices; (b) functional performance, including the effectiveness in serving the people, activities, and processes housed, and in supporting the relationships among them; (c) formal/physical performance, including the effectiveness of the site layout, spatial solution, and technologies, equipment, materials, and other resources used; (d) cost performance, including total installed costs (TIC), operations and maintenance costs (O&M), and life cycle costs; (e) time performance, including total delivery cycle time, and service life span; (f) performance from a quality and reliability perspectives, including the satisfaction of all current and future stakeholders, and the prevention of partial or total failures; (g) safety and security performance, including protection of people, property, and the environment, and protection from natural and human-caused eventualities; (h) risk performance, which defines targeted levels of unacceptable and prudent reversible risks; (i) constructability and procurability performance; (j) commissioning, operability, and maintainability performance; (k) performance from

a health perspective; and (l) sustainability performance, which defines targeted levels of resource use and consumption, waste generation and accumulation, and environmental impact.

- There are six principal categories of influences that affect or can affect the short-term and long-term performance of a F&CIS project: (a) project characterization, which defines the specific features, attributes, characteristics, and qualities of a capital project as defined by the project's industry sector and specific project type; (b) the project objectives, which defines the integrated set of goals and objectives for the project, from an institutional, sub-organizational units, functional groups, individual team members, and external stakeholders perspectives; (c) the project scope, which defines the project's specific needs (primarily quantitative data and information), facts (constraints), preliminary concepts or strategies for achieving the goals, satisfying the needs, and working within the facts, and areas of potential problems and opportunities; (d) the physical context of the project, which defines the project's geographical location, surface and subsurface conditions, environmental issues, existing infrastructure of utilities and services, and surrounding activities and assets; (e) the non-physical context of the project, which defines the community, social, and political issues, and public relations, economic and financial issues, legal, regulatory, and policy issues, and industrial and technological issues, including the availability of labor, materials, equipment, and technologies that surround the project; (f) the set of project risks, which defines the impact and probability of risks stemming from products used and processes followed in the project, risks stemming from the contract terms and conditions, and risks stemming from construction operations, processes and activities.
- There are six principal categories of stakeholders in a F&CIS project: (a) the Owner Team, whose perspective provides the key point of departure for the PDP; (b) the Users/Operations Team, whose perspective ensures that issues that will affect or have a potential to affect the operations and maintenance processes are addressed in a proactive way in the initial stages of the project; (c) the Design Team, composed of engineers, architects, and other specialty designers, whose perspective ensures that issues that will affect or have a potential to affect the design process are addressed in a proactive way in the initial stages of the project; (d) the Construction Team, composed of construction managers, general contractors, and specialty contractors or subcontractors, whose perspective ensures that issues that will affect or have a potential to affect the construction process are addressed in a proactive way in the initial stages of the project; (e) the Team of Vendors and Suppliers, whose perspective ensures that issues that will affect or have a potential to affect the procurement process are addressed in a proactive way in the initial stages of the project; and (f) the External Parties, composed of the financial institutions, insurance and bonding companies, regulatory agencies, the community, the general public, and other parties that can affect or have a potential to affect the performance of the project, whose perspective ensures a smoother internal/external project interface.
- The process for developing a PDP has three phases: (a) formation, which, through a process of alignment and consensus building, establishes the owner and user/operator perspectives on the project, using the enterprise's vision, mission, strategic plan, and business plan as a point of departure; (b) communication, which, also through a process of alignment and consensus building, adds the design, construction, procurement, and external parties perspectives; and (c) integration, which, also through a process of alignment and consensus building, establishes the integrated PDP that will guide project execution.

- To fully achieve integrated project definition, there is a need to begin with a clear understanding of the regulatory context of a F&CIS project (codes, standards, and regulations), the client, the A/E systems designer, the constructor, and the supply chain. With these five elements defined, project definition starts with the development of a project definition package (PDP), a project execution plan (PEP), a design package (DP), and a production process plan (PPP). The DP is the mechanism through which the project is defined from a product perspective, and the PPP is the mechanism by which the project is defined from a process perspective. These four elements converge in a work breakdown structure (WBS). In addition, four models emerge: (a) 3D model of the project, (b) cost model of the project, (c) time model of the project, and (d) production process model. These four models need to come together in an integrated project definition model (IPDM).
- To enhance the design process, there is a need to incorporate several enhancements to the traditional design process (i.e., from conceptual through schematic and design development, to contract documents). These enhancements include: (a) clear understanding and definition of three special processes that regulate the flow of information as the design solution evolves (the analysis, generation, evaluation, selection, and specification process, the decision-making process, and the conflict resolution process; (b) incorporation of a formal, explicit, and systematic performance parameters check to evaluate how the design solution at every design phase milestone responds to the baseline parameters for performance established in the PDP; and (c) formal, explicit, systematic input of data/information and knowledge/experience from a construction, procurement, commissioning, operations, maintenance, health, and sustainability points of view.
- To enhance the construction process, there is a need to understand construction as a closed-system production process. This process begins with an understanding and definition of three types of external influences: (a) influences on construction project planning; (b) influences on the construction resources supply chain; and (c) influences on project execution. After influences have been defined, the focus of construction is on four types of functions: (a) control functions to regulate flow of inputs to achieve desired results, and establish work processes to change inputs to outputs; (b) acquisition of all resources and services required for the project, including transport, receipt, inspection and storage; (c) distribution of all required resources to the appropriate crews; and (d) conversion of inputs to outputs using work processes. This production process can further be enhanced by incorporating mechanisms to recover, repair, reuse, and maintain partially-consumed resources, while maximizing the recovery of recyclable waste and minimizing the amount of non-recyclable waste generated in the project. Finally, it is necessary to also be aware of the influences that the project will have on its external context and on its stakeholders.
- To implement an infrastructure that supports a learning organization approach within any organization involved in a F&CIS project, there is a need to establish: (a) an institutionalized program at an enterprise and project levels, for the transfer of data/information and knowledge/experience from past projects to new projects through principles, concepts, guidelines, standards, best practices, lessons learned, and strategies; and (b) an integrated multimedia system for acquisition, processing, maintenance, dissemination, and application of the data/information and knowledge/experience gained internally and externally.
- A global finding as the research program under this award evolved is that research in the A/E/C industry tends to be: (a) problem-specific – focused on very specific problem areas with narrowly-defined scopes and boundaries; (b) discipline-specific – driven by individuals or teams from very specific engineering or science disciplines with limited participation from disciplines outside the specific domains of the research team; (c) fragmented and isolated – either basic or applied, but

rarely both; limited integration not only between engineering and science, but also among the multiple disciplines within each; and rarely having a cradle-to-grave vision, much less a cradle-to-cradle vision; (d) contextually-independent – self-centered with limited participation of the ultimate users and customers of research findings as active participants in the research process; (e) short-term – with very short or limited time frames; (f) evolutionary – conservative and built upon today’s knowledge base, rather than taking risks and pursuing the next-generation knowledge; and (g) funding source-dependent – responding to the specific requirements of a funding agency, which many times is the cause of these characteristics.

- A global finding as the teaching program under this award evolved is that education in the A/E/C industry tends to be: (a) discipline- and course-specific – driven by very specific math, science, engineering, and humanities discipline areas; having narrowly-defined scopes and boundaries within each course in a curriculum; and providing limited opportunities for interdisciplinary interaction among students and educators from various disciplines; (b) contextually-independent – emphasize the theoretical side of topics with limited exposure to their practical side; provide limited opportunities to bring the “real world” into the classroom; or of bringing the classroom into the “real world”; (c) teaching-driven – focus on the role of the educator in delivering course content material, instead of focusing on the role of the educator in enabling learning outcomes based on course content; (d) linear – having a hierarchical structure that builds upon previous levels of education; lacking mechanisms for reflection, synthesis, and integration as students progress towards higher levels of education; and having minimal involvement, input, and feedback from those that have reached the higher levels of education; (e) ineffective and inefficient – based on pedagogical models that worked adequately in the past, but that are no longer responsive to the challenges facing society; having limited access and exposure for educators and students to the technological requirements for professional practice in business, industry, and government; emphasizing research at the expense of teaching and practical experience, especially in undergraduate education; increasingly bureaucratic and costly, while resources are becoming increasingly scarce; and increasingly competitive and costly for students, limiting their accessibility to the educational process; (f) fragmented and isolated – limited institutional collaboration among and within educational institutions engaged in K-12 education, undergraduate education, and education for life long learning; lacking integration of curricular content among and within these three education levels; (g) institution-dependent – respond to the specific context and culture of the educational institution, which many times is the cause of these characteristics; and (h) non-diversity-oriented – not attractive to members of society who will constitute the largest increase in population and workforce over the next several decades; put simply, the A/E/C industry is not currently attracting large numbers of women and minorities

Training and Development, and Outreach Activities

Training and Development Activities

[This section summarizes how the program under this award has contributed to the research and teaching skills and experience of those who have worked on the project.]

A fundamental objective of the research and teaching program under this award was the explicit and formal integration of research, teaching, and practice. Consequently, all activities (described previously) have contributed to enhance the research, teaching, and practice skills and experience of a diverse group of people who have participated in, contributed to, and benefited from them in multiple ways:

- undergraduate, graduate, and doctoral students at Purdue University and at Georgia Tech, who were involved as assistants in research and teaching activities: (a) performing literature reviews, (b) collecting, synthesizing, and analyzing data, and (c) developing new knowledge individually within a specific knowledge domain, or in multi- and interdisciplinary teams across various knowledge domains
- undergraduate and graduate students at Georgia Tech and at other universities in the U.S. and in other countries, who have been the recipients of: (a) new course developments, (b) new curriculum developments, and (c) enhancements to the teaching and learning processes
- faculty who collaborated in various research and teaching activities both as individuals and as members of multi- and interdisciplinary teams: (a) within the School of Civil and Environmental Engineering at Georgia Tech, (b) from other schools within the College of Engineering at Georgia Tech, (c) from other colleges at Georgia Tech, and (d) from other universities in the U.S. and in other countries
- middle and high school teachers from the Atlanta Metropolitan Area, who received training in research, in the use of educational multimedia technology, and in the application of new pedagogical approaches to the classroom, and by extension their middle and high school students
- practitioners (e.g., from public and private sector owner, A/E design, and construction organizations) in the A/E/C industry in the U.S. and other countries who have been contributors to the development of continuing education programs, courses, and workshops, or participants in them

Outreach Activities

[This section summarizes activities within the program under this award aimed to reach out to members of communities who are not usually aware of these activities, for the purpose of enhancing participation in science learning and careers in science, public understanding of science and technology.]

The program under this award has provided a solid foundation for a comprehensive outreach program at Georgia Tech, at other academic institutions and organizations in the U.S. and other countries, and through invited keynote lecturers, invited lectures and speeches, and other special activities.

Current On-going Outreach Activities at Georgia Tech

- As the Fred and Teresa Estrada Young Professor in the College of Engineering (CoE) at the Georgia Institute of Technology (Georgia Tech), Dr. Vanegas is (a) developing a focused, multi-disciplinary, and self-sustaining institutional infrastructure for sustainable affordable housing education, research, and outreach for the U.S. and the Americas; (b) mentoring and advising the Hispanic Student Community within the CoE, and other colleges as the Faculty Advisor for the Society of Hispanic Professional Engineers Student Chapter at Georgia Tech; and (c) establishing closer links between Georgia Tech and the professional Hispanic and general Hispanic communities in the Southeast.
- As Co-Director of the Construction Resource Center (CRC), formerly the Construction Research Center, since 1997, Dr. Vanegas is developing and implementing an integrated, quality-driven, interdisciplinary, and institute-wide research and education infrastructure to advance the knowledge

and practices of the Architectural, Engineering and Construction (A/E/C) industry, through a strong industry/academic partnership, toward more effective and efficient delivery of sustainable, cost-effective facilities and civil infrastructure to individuals, communities, and organizations locally, nationally, and internationally. The CRC is an information and knowledge enterprise that provides research and education capabilities to any organization involved in construction-related activities, to enhance the effectiveness and efficiency of its operations, develop and implement advanced technologies, and be more competitive and profitable. CRC capitalizes on the complete multidisciplinary resource base of the Georgia Institute of Technology, through a joint collaboration of the CoA and the CoE, through their Building Construction Program (BC) and the CEM Program in CEE, respectively, and internal partnerships established with various other academic and research units.

- As the Group Leader of the Construction Engineering and Management (CEM) Program of the School of Civil and Environmental Engineering (CEE) since 1994, Dr. Vanegas is teaching undergraduate, graduate, and continuing education courses, and also leading and managing an active research program on: (a) advanced strategies and technologies for sustainable land development, and for planning, design, and construction of sustainable facilities and civil infrastructure systems, with an emphasis on sustainable affordable housing; (b) design/construction integration in the development and rehabilitation of facilities and civil infrastructure systems; (c) advanced strategies, tools and methods for effective management of capital projects; (d) constructability programs and advanced technologies for modularization and pre-assembly; and (e) undergraduate, graduate, and professional continuing education curricula development.
- As a Research Associate in the Institute for Sustainable Technology and Development (ISTD) at Georgia Tech, formerly the Center for Sustainable Technology (CST), Dr. Vanegas is leading an effort in environmentally conscious design and construction for F&CIS, partially funded by the Georgia Research Alliance.
- As a Guest Fellow with the Army Environmental Policy Institute (AEPI) at the Georgia Institute of Technology, Atlanta, Georgia, Dr. Vanegas is leading an effort for sustainable army installations policy development and implementation, since 1999.

Current Outreach Activities in the U.S. and Other Countries

- Dr. Vanegas has developed alliances and partnerships with organizations around the world, and has participated in, or contributed to, numerous of their programs, activities, and events, including: (a) the World Engineering Partnership for Sustainable Development (WEPSD), (b) the World Federation of Engineering Organizations (WFEO), (c) the Pan American Federation of Engineering Societies (UPADI), (d) the Inter American Development Bank (IDB), (e) the Regional Center for Engineering for Sustainable Development in Uruguay, (f) the Tweed Horizons Institute for Sustainable Development in Scotland, (g) the American Association of Engineering Societies (AAES), (h) the Engineering Foundation (EF), and (i) the Civil Engineering Research Foundation (CERF).
- Dr. Vanegas is an active member of various professional organizations, and has participated in, or contributed to, numerous of their programs, activities, and events, including: (a) the American Society of Civil Engineers (ASCE), (b) the ASCE the Construction Research Council (CRC), (c) the American Society for Engineering Education (ASEE), (d) the Project Management Institute (PMI),

(e) the Urban Land Institute (ULI), (f) the International Association of Bridge and Structural Engineers (IABSE), and (g) the Society of Hispanic Professional Engineers (SHPE).

- Dr. Vanegas currently contributes to several research and education initiatives, including (a) serving the Georgia Tech Link for the Center for Hemispherical Cooperation in Research and Education in Engineering and Applied Science (COHEMIS) at the University of Puerto Rico-Mayagüez, Mayagüez, Puerto Rico, since March 1999; (b) being a member of the Curriculum Advisory Committee for Leadership for Environment and Development (LEAD) International, Inc., New York, New York, since January 1999; (c) being an active member of the Engineers Forum for Sustainable Development, a joint effort between AAES and ASEE, with support from the National Academy of Engineering (NAE); and (d) being a member of the External Advisory Committee for the Civil Infrastructure Research Center at the University of Puerto Rico-Mayagüez, Mayagüez, Puerto Rico, since April 1993.
- Dr. Vanegas is a regular contributor to the research and educational deployment efforts of the Construction Industry Institute (CII) in the areas of innovative practices for cost-effective capital projects, constructability, and modularization, and to the professional education programs of the Local User Councils of the Business Roundtable (BRT).
- Dr. Vanegas is regularly invited by different academic institutions, organizations, and companies within the U.S. and abroad, as consultant, and as developer and instructor of continuing education courses for professionals in the A/E/C and other industries.
- Dr. Vanegas has been a Special Academic Consultant to The Winter Group of Companies (Winter Properties, The Winter Construction Company, and Winter Environmental Services), Atlanta, Georgia, since 1998.

Past Outreach Activities in the U.S. and Other Countries

- Dr. Vanegas has been a contributor to the Initiative for Community Outreach, Research, and Education (ICORE), a multidisciplinary collaborative effort under the leadership of the Georgia Tech Research Institute, with Georgia Tech's colleges and schools, communities, industries, and businesses in urban and rural areas, to (a) build a community-integrated research and development program focused on the restoration of environmentally impaired properties within an overall context of community revitalization; and (b) address the needs of communities throughout Georgia, the Southeast, and nationally.
- Dr. Vanegas has been a Visiting Eminent Scholar at the (a) Del E. Webb School of Construction, Arizona State University, Tempe, Arizona; (b) Facultad de Ingeniería, Programa de Maestría en Construcción, Universidad Autónoma de Yucatán, Mérida, Mexico; (c) Escuela de Ingeniería Civil y Administración, Programa de Maestría en Administración de la Construcción, Universidad Panamericana – Sede Guadalajara, Guadalajara, Mexico; and (d) Departamento de Ingeniería Civil, Programa de Maestría en Construcción, Universidad de los Andes, Santafé de Bogotá, Colombia.
- Dr. Vanegas was a consultant to the Inter American Development Bank, Washington, D.C., for the Development of Feasibility Study for the Establishment of a Regional Center for Engineering for Sustainable Development in Uruguay.
- Dr. Vanegas has contributed to several initiatives of (a) the National Chamber of the Mexican Construction Industry, (b) the Mexican Construction Industry Foundation, and (c) the National Chamber of the Colombian Construction Industry

- Dr. Vanegas was an invited participant to the 1994 Civil Engineering Education Workshop on "*Re-Engineering Civil Engineering Education: Goals for the 21st Century*," sponsored by the 1995 ASCE Education Conference Steering Committee and the 1994 CE Education Workshop Committee, held at The University of Texas at Arlington, September 1994.

Invited Keynote Lecturer/Speaker, No Paper Published

- Vanegas, J. (2000) "*Sustainability in the Built Environment: A Blueprint for Action*," The Howard S. Wright Lecture in the College of Architecture and Urban Planning, University of Washington, Seattle, Washington; March, 2000
- Vanegas, J. (2000) "*Globalization and Sustainable Development: A Greenprint for Action*," Keynote Lecture at the V Mexican, Central American and the Caribbean Congress of Deans of Engineering and Industry Leaders & the XII International Congress of Engineering, UNESCO, Puebla, Mexico; January, 2000
- Vanegas, J. (1999) "*Sustainability and Civil Engineering: From Concept to Action*," Keynote Lecture at the International Association for Bridge and Structural Engineering Symposium: Structures for the Future – The Search for Quality, Rio de Janeiro, Brazil, August, 1999

Invited Lecturer/Speaker, No Paper Published

- "Technology Transfer" lecture presented at the Fourth International Civil Engineering Symposium, Instituto Tecnológico de Estudios Superiores del Occidente (ITESO), Tlaquepaque, Jalisco, México, March 1999
- "The Civil Engineer as Leader for Sustainable Development" lecture presented at the Sixth International Civil Engineering Symposium, Instituto Tecnológico de Estudios Superiores del Occidente (ITESO), Tlaquepaque, Jalisco, México, March 1999
- "The Civil Engineer as Leader for Sustainable Development" lecture presented at the X Congreso Nacional de Colegios de Ingenieros Civiles, Federación de Colegios de Ingenieros Civiles de la República Mexicana, A.C., Mexicali, Mexico, November 1998
- "Context, Challenges, and Opportunities of Sustainable Development and Technologies," lecture presented at the 11th International Congress of Mechanical Engineering, Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM), Monterrey, Nuevo León, Mexico, October 1998
- "Effective and Efficient Construction Project Management in Crisis Times: Advanced Strategies and Tools," lecture presented at the 1998 Asamblea Nacional de la Cámara Colombiana de la Industria de la Construcción (CAMACOL), Cali, Colombia, October 1998
- "Standardization of Industrial Processes for Construction Materials and Products," lecture presented at the 1998 Asamblea Nacional de la Cámara Colombiana de la Industria de la Construcción (CAMACOL), Cali, Colombia, October 1998
- "A Virtual Consultant for Technological Innovation in Construction" lecture presented at the TecnoMex '98 International Symposium, sponsored by the Fundación Nacional de la Industria de la Construcción, Ciudad de México, México, February 1998.
- "Technological Development in the Construction Industry" lecture presented at the Fifth National Civil Engineering Congress, Universidad de la Américas, Cholula, Puebla, México, January 1998.
- "A New Paradigm for A/E/C Practice: Trends, Challenges, and Opportunities" lecture presented at the Lord, Aeck & Sargent, Inc., Architecture, 1998 State-of-the-Firm Meeting, Atlanta, Georgia, January 1998
- "A Framework for Integration for the A/E/C Industry," presentation to the U.S. Department of Transportation, Washington D.C., December 1997
- "Value Engineering, Value Added, and Earned Value," lecture presented at the Bufete Industrial 1997 Annual Executive Retreat, México City, México, December 1997

- *"A New Paradigm for Assessing the Performance of Engineering and Construction Companies ,"* lecture presented at the Bufete Industrial 1997 Annual Executive Retreat, México City, México, December 1997
- *"Towards the Creation of an Integrated Civil Infrastructure Systems Community,"* lecture presented at the Fifth Infrastructure Lecture Series of the Civil Infrastructure Research Center (CIRC) of the University of Puerto Rico - Mayagüez, Mayagüez, Puerto Rico, November 1997
- *"Integrating Sustainable Development into the Civil Engineering Curriculum,"* presentation in the Sustainable Development Track – Session SD7, ASCE 1997 Annual Convention and Exposition, Minneapolis, Minnesota, October 1997
- *"Real Estate/Construction – The Future,"* lecture presented at the 1997 Management Seminar of The Winter Construction Company, Atlanta, Georgia, October 1997
- *"Georgia Tech Report on Sustainability Initiatives,"* plenary presentation at the International Conference on Engineering Education and Training for Sustainable Development - Towards Improved Performance, Paris, France, September 1997 (based on contributions from Jean-Lou Chameau, Jorge Vanegas, Carol Foley, and Leigh McElvaney)
- *"The Changes in Undergraduate Engineering Education: Towards a New Paradigm for the New Millennium...,"* lecture presented at the Seminar on Covering Math and Science Education of the Hechinger Institute on Education and the Media, Teachers College – Columbia University, New York City, New York, September 1997
- *"Advanced Technologies for Construction of Infrastructure,"* lecture presented at the 60th Anniversary of the College of Engineering, V Civil Engineering Week, Universidad Autónoma de Yucatán (UADY), Mérida, México, July 1997.
- *"Integral Preparation of Civil Engineers within a Global Conceptual Framework,"* lecture presented at the 60th Anniversary of the College of Engineering, V Civil Engineering Week, Universidad Autónoma de Yucatán (UADY), Mérida, México, July 1997.
- *"Challenges and Opportunities for Civil Engineering in the 21st Century,"* lecture presented at the 60th Anniversary of the College of Engineering, V Civil Engineering Week, Universidad Autónoma de Yucatán (UADY), Mérida, México, July 1997.
- *"Constructability – A Conceptual Framework,"* lecture presented at the Greater New Orleans Business Roundtable May Workshop, New Orleans, Louisiana, May 1997
- *"Constructability – A Tool for Management and Control of Construction Projects,"* lecture presented at the Second National Civil Engineering Symposium , Instituto Tecnológico de Estudios Superiores del Occidente (ITESO), Tlaquepaque, Jalisco, México, April 1997
- *"Challenges and Opportunities for Civil Engineering in the 21st Century,"* lecture presented at the Second National Congress of Civil Engineering Students, Universidad Iberoamericana, México City, México, April 1997
- *"A Conceptual Framework for Integration in Construction Projects,"* lecture presented at the Bufete Industrial 1996 Annual Executive Retreat, México City, México, December 1996
- *"A Framework for Global Cooperation for Sustainable Development"* lecture presented at the International Seminar on Communications and Sustainable Development, sponsored by the Centro Regional de la Ingeniería para el Desarrollo Sostenible (CRIDS) and the World Federation of Engineering Organizations (WFEO), Montevideo, Uruguay, November, 1996.
- *"New Technologies and Best Practices for Housing Developments,"* special workshop prepared for Grupo GEO, México City, México, November 1996
- *"Models in Global Cooperation for Sustainable Development"* lecture presented at the XXIV Panamerican Convention of Engineers, and the II Panamerican Congress on Sustainable Development, sponsored by the Panamerican Federation of Engineering Organizations, San José, Costa Rica, August, 1996.
- *"2% Engineering Costs - Can It Work for You?"* breakout presentation of Research Team 112 at the 1996 Annual Conference of the Construction Industry Institute, Toronto, Canada, August, 1996.
- *"New Technologies for Construction"* lecture presented at the Tecno Mex '96 International Symposium, sponsored by the Fundación Nacional de la Industria de la Construcción, Ciudad de México, México June, 1996.

- *"Advanced Techniques for Effective Construction Management,"* lecture presented at the Fourth Infrastructure Lecture Series of the Civil Infrastructure Research Center (CIRC) of the University of Puerto Rico - Mayagüez, Mayagüez, Puerto Rico, April 1996
- *"Future Building - Construction Beyond the 1990's,"* lecture presented at the 1995 Superintendent's Conference of The Holder Corporation, Atlanta, Georgia, October 1995
- *"Challenges and Opportunities for the Construction Industry in the 21st. Century,"* lecture presented at the 1995 Management Seminar of The Winter Construction Company, Atlanta, Georgia, October 1995
- *"Challenges and Opportunities for the Construction Industry in the 21st. Century,"* special seminar presented to a Korean Delegation of construction project managers, sponsored by the Korean Institute of Project Management and Technology, Atlanta, Georgia, October 1995
- *"Challenges and Opportunities for the Construction Industry in the 21st. Century,"* lecture presented at the III Construction Fair and Exposition, sponsored by the Cámara Colombiana de la Industria de la Construcción (CAMACOL)-Atlántico, and the Servicio Nacional de Aprendizaje (SENA), Barranquilla, Colombia, August 1995
- *"Construction Engineering and Management Education and Research Programs at Georgia Tech,"* presentation to the Professional Construction Estimators Association (PCEA), Atlanta, Georgia, April 1995
- *"Sustainable Development,"* presentation to the Environment Committee of the Atlanta Chapter of the American Institute of Architects (AIA), Atlanta, Georgia, April 1995
- *"Trends in Engineering Education for the 21st Century:,"* lecture presented in Technical Session 1 of the South Atlantic Regional Conference of the Society of American Military Engineers, Callaway Gardens, Georgia, March 1995
- *"Caring for Mother Earth: Sustainable Living,"* Educational Session within the Science for the City Environmental Literacy Conference: From Knowledge to Action, Center for Disease Control, Atlanta, Georgia, February 1995
- *"A Tutorial on Multimedia Theory and Applications,"* lecture presented in Technical Session 88A of the Transportation Research Board 74th Annual Meeting, Washington D.C., January 1995
- *"A Framework for Analyzing Environmental Life Cycle Costs,"* lecture presented at a EPA Pollution Prevention/Waste Minimization Conference, Atlanta, Georgia, December 1994
- *"Overview of Sustainable Development,"* lecture presented at the 1994 Summer Seminar of the Georgia Section of the Institute of Transportation Engineers, in the session Planning for the Next Generation: Sustainable Development and the Environment, Savannah, Georgia, July 1994
- *"Multimedia Strategies for Engineering and Construction: A Tutorial,"* (Co-Speaker) special tutorial session 10W2 of the ASCE First Congress on Computing in Civil Engineering, Washington, D.C., June 1994
- *"Using Constructability Lessons Learned for Infrastructure Rehabilitation,"* lecture presented at the Third Infrastructure Lecture Series of the Civil Infrastructure Research Center (CIRC) of the University of Puerto Rico - Mayagüez, Mayagüez, Puerto Rico, April 1994
- *"Educational Module on Implementing Constructability in the Utility Industry,"* presentation to the Electric Power Research Institute (EPRI) 3rd International Conference on Fossil Plant Construction, Tampa, Florida, October 1993
- *"Application of Optical Imaging for Project Management,"* presentation to the Technology Subcommittee of the Edison Electric Institute (EEI) at the Fall Construction Committee meeting, San Francisco, California, September 1993
- *"Educational Module on Implementing Constructability in the Utility Industry,"* presentation to the Technology Subcommittee of the Edison Electric Institute (EEI) at the Fall Construction Committee meeting, San Francisco, California, September 1993
- *"Educational Module on Implementing Constructability,"* presentation to the Construction Industry Institute Implementation Workshop, Austin, Texas, June 1993

- *"An Integrated Design/Construction Research Program for Infrastructure Rehabilitation,"* presentation to the Technology Subcommittee of the Edison Electric Institute (EEI) at the Spring Construction Committee meeting, Indianapolis, Indiana, May 1993
- *"An Integrated Design/Construction Research Program for Infrastructure Rehabilitation,"* lecture presented at the Second Infrastructure Lecture Series of the Civil Infrastructure Research Center (CIRC) of the University of Puerto Rico - Mayagüez, Mayagüez, Puerto Rico, April 1993
- *"A Model for a Collaborative Research Partnership among Industry, Government and Academia for Infrastructure Rehabilitation,"* lecture presented at the Colegio de Ingenieros and the AGC of Puerto Rico, San Juan, Puerto Rico, April 1993
- *"Multimedia Strategies for Engineering and Construction: A Tutorial,"* lecture presented in Technical Session 106 of the Transportation Research Board 72nd Annual Meeting, Washington D.C., January 1993
- *"Use of Multimedia in Construction Engineering and Management Education,"* presentation to the Construction Research Council at the ASCE 1992 Annual Convention, New York City, New York, September 1993

Other Special Activities

- *An Integrated Design/Construction Research Program for Infrastructure Rehabilitation,* Poster Session, Industry/University Innovation Workshop, sponsored by the National Science Foundation (NSF) and the Civil Engineering Research Foundation (CERF), held in Washington D.C., October 1997
- *A Curriculum for Infrastructure Assessment, Rehabilitation, and Reconstruction,* Poster Session, ASEE 1995 Annual Conference, American Society for Engineering Education, Anaheim, California
- *Curriculum for an Integrated Course Sequence in Sustainable Development and Technology,* National Science Foundation Project Showcase, ASEE 1995 Annual Conference, American Society for Engineering Education, Anaheim, California
- *A Curriculum for Infrastructure Assessment, Rehabilitation, and Reconstruction,* Poster Session, ASCE 1995 Education Conference, American Society of Civil Engineers, Denver, California

Publications and Products

Publications

[This section lists publications resulting directly and indirectly from the research and teaching activities and findings of the program under this award.]

Selected Journal Publications

- Vanegas, J., Principal Author (1997) *"2% Engineering-Can It Work for You?"* Research Summary of Cost Effective Engineering Research Team, The Construction Industry Institute (CII), University of Texas-Austin, CII Publication 112-1 (This publication was reviewed by the CII Product Review Board)
- Hastak, M., Halpin, D., and Vanegas, J. (1996) *"COMPASS: A New Paradigm for Project Cost Control Strategy and Planning,"* Journal of Construction Engineering and Management, (ASCE), Vol. 122, No. 3, pp. 254-264
- Reyna, S., Vanegas, J., and Khan, A. (1994) *"Construction Technologies for Sewer Rehabilitation,"* Journal of Construction Engineering and Management, (ASCE), Vol. 120 No. 3, pp. 467-487
- Reyna, S., Delleur, J., and Vanegas, J. (1994) *"Multi-attribute Rehabilitation of Storm or Combined Sewer Systems,"* in Urban Drainage Rehabilitation Programs and Techniques, edited by William A. Macaitis, (ASCE), pp. 55-72

- Vanegas, J., Halpin, D., and AbouRizk, S. (1994) "Integrating Process Simulation into Construction Engineering Education," *European Journal of Engineering Education*, Vol. 19/1, pp. 51-67
- Hastak, M., Vanegas, J., and Puyana-Camargo, M. (1993) "Time-Based Competition: A Competitive Advantage Tool for A/E/C Firms," *Journal of Construction Engineering and Management*, (ASCE), Vol. 119 No. 4, pp. 785-800
- Vanegas, J., Bravo, E., and Halpin, D. (1993) "Simulation Technologies for Planning Heavy Construction Processes," Special Issue of the *Journal of Construction Engineering and Management*, (ASCE), Vol. 119 No. 2, pp. 336-354

Peer-Reviewed Conference Publications

- Vanegas, J., and Pearce, A. (2000) "Drivers for Change: An Organizational Perspective on Sustainable Construction," *Proceedings of the ASCE Construction Congress VI*, American Society of Civil Engineers, Reston, Virginia, pp. 406-415
- Pearce, A., Gregory, R., and Vanegas, J. (2000) "Resource Allocation and Problem Prioritization for Sustainable Facilities and Infrastructure," *Proceedings of the ASCE Construction Congress VI*, American Society of Civil Engineers, Reston, Virginia, pp. 396-405
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- Frost, J., and Vanegas, J., (1994), "*Workshop on Environmental Life Cycle Cost Estimating for Weapons Systems*," Final Technical Report submitted to Delta Research Corporation, Georgia Institute of Technology, Atlanta, Georgia, 30 pp.

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- Vanegas, J. (1994) "*Georgia Tech and SHPE: A Partnership for Excellence in Engineering Education for Hispanics for the 21st Century*," article for the Hispanic Engineer Magazine, Mellado Communications, Monterey Park, California, April Issue

Web Site

A general public access Web Site for dissemination of activities, findings, publications, and products directly related to the program under this award is currently being developed, but is not available yet.

Products

[This section lists tangible products resulting directly and indirectly from the research and teaching activities and findings of the program under this award.]

Research Products

The multi- and interdisciplinary collaborative research infrastructure and environment established at Georgia Tech using the activities and findings of the program under this award as a solid foundation, is currently supporting the research, development, testing, and validation of the following research products:

- a model for integrated analysis, evaluation, and development of guidelines and recommendations for policies, standards, codes, and regulations influencing or affecting the total life cycle of affordable housing solutions, from an environmental quality and performance perspective. Target audience: policy-makers, regulators, A/E/C industry stakeholders (owners, designers, constructors)

- a multi-attribute decision making model for integrated life cycle environmental quality and performance assessment at all stages of the total life cycle of affordable housing solutions, which incorporates, in a holistic way, factors such as risk, cost, time, quality, safety, environmental impact, and patterns of behavior and use. Target audience: policy-makers, regulators, developers of affordable housing in the public and private sectors, A/E/C professionals
- an integrated test and evaluation systems-based model for determining the effectiveness and suitability of affordable housing solutions in meeting environmental quality and performance standards (e.g., energy efficiency, indoor air quality, impacts on human health, etc.), while satisfying specific user needs and requirements. Target audience: developers of affordable housing in the public and private sectors, A/E/C professionals
- life-cycle profiles of integrated environmental and economic sustainability for building technologies, systems, products and materials for affordable housing solutions. Target audience: developers of affordable housing in the public and private sectors, A/E/C professionals, manufacturers and suppliers
- tools for virtual and rapid visualization, modeling, prototyping, and simulation at each stage of the total life cycle of affordable housing solutions, from an environmental quality and performance perspective. Target audience: developers of affordable housing in the public and private sectors, A/E/C professionals
- modular design and construction solutions for disassembly, recycle and/or reuse of affordable housing solutions. Target audience: developers of affordable housing in the public and private sectors, A/E/C professionals, manufacturers and suppliers
- alternative new products and materials for affordable housing solutions made from recovered construction demolition waste, and/or other waste sources. Target audience: developers of affordable housing in the public and private sectors, A/E/C professionals, manufacturers and suppliers
- alternative new construction technologies, equipment, and methods for affordable housing solutions that minimize negative environmental impacts. Target audience: developers of affordable housing in the public and private sectors, A/E/C professionals, manufacturers and suppliers
- advanced sensing and control technologies for real-time continuous measurement, documentation, and management of environmental performance (e.g., indoor air quality, energy use and efficiency, water quality, waste generation, etc.) of affordable housing solutions. Target audience: regulators, developers of affordable housing in the public and private sectors, A/E/C professionals, manufacturers and suppliers
- a global on-line multimedia system for acquisition, storage, and retrieval of lessons learned and best practices regarding life cycle environmental quality and performance of affordable housing solutions. Target audience: policy-makers, regulators, A/E/C industry stakeholders, manufacturers and suppliers
- a comprehensive technology transfer and dissemination program for the A/E/C industry on environmentally conscious affordable housing solutions, and environmentally conscious building technologies, systems, products and materials for them. Target audience: policy-makers, regulators, A/E/C industry stakeholders, manufacturers and suppliers

- a comprehensive education program for pre-college students, undergraduate and graduate students, educators, professionals, and the general public, on planning, design, construction, operation and maintenance, rehabilitation, reuse and/or disposal of environmentally conscious affordable housing solutions. Target audience: policy-makers, regulators, A/E/C industry stakeholders, manufacturers and suppliers

In addition, plans are under way for:

- launching entrepreneurial new business enterprises to (a) service all stages of the life cycle of innovative and environmentally conscious affordable housing solutions, and (b) develop, test, and manufacture innovative and environmentally conscious building technologies, systems, products and materials for affordable housing
- opening new opportunities for global commercialization of these services, building technologies, systems, products and materials,
- attracting additional private and public sector investments to support the collaboration on an on-going basis, and
- establishing a comprehensive technology transfer, education, and dissemination program for between Georgia Tech and countries in North, Central, and South America and the Caribbean

Educational Modules for Continuing Education

- *Construction Planning for Start-up and Work Packaging for Project Control*, 8 hrs., based on published CII Educational Modules, for the Greater New Orleans Business Roundtable, sponsored by the Department of Civil and Environmental Engineering at the University of New Orleans New Orleans, Louisiana; Invited Instructor
- *Modularization in Industrial Construction*, based on published CII Educational Module, sponsored by the Northwest Indiana Business Roundtable, Schererville, Indiana; Invited Instructor
- *Project Alignment and Partnering Development*, and *Project Alignment and Partnering Maintenance*, a process and manual for capital project alignment and partnering seminars (16 hrs.) developed for U.S. Steel Gary Works, Gary, Indiana, 1999; Author and Instructor
- *Administración Efectiva y Eficiente de Proyectos de Construcción en Epocas de Crisis: Estrategias y Herramientas de Avanzada (Effective and Efficient Construction Project Management in Crisis Times: Advanced Strategies and Tools)*, a workshop (8 hrs.) in Spanish developed and customized for the Cámara Colombiana de la Industria de la Construcción (CAMACOL)-Seccional Caldas, Manizalez, Colombia, 1998; Author and Instructor
- *Managing Uncertainty and Team Dynamics*, 8 hrs., based on published CII Educational Modules, for the Greater New Orleans Business Roundtable, sponsored by the Department of Civil and Environmental Engineering at the University of New Orleans, New Orleans, Louisiana; Invited Instructor
- *Estrategias, Técnicas, y Herramientas de Avanzada para el Manejo Efectivo de Proyectos (Advanced Strategies, Techniques, and Tools for Effective Project Management)*, an educational module (16 hrs.) in Spanish developed and customized for Industria de Trabajos Eléctricos, S.A. de C.V. a division of Siemens Energy & Automation, Inc., Juárez, Mexico, 1998; Author and Instructor
- *Organizational Structures for Effective Project Management and Constructability*, an educational module (8 hrs.) developed for Ingenieros Civiles Asociados (ICA), through the Universidad Nacional Autónoma de Mexico (UNAM), Mexico City, Mexico, 1998; Author and Instructor
- *Taller Ejecutivo de Innovación Tecnológica: Sistema de Tecnología Empresarial para ICA (Executive Workshop for Technological Innovation: An Enterprise Technological System for ICA)*, a workshop (24 hrs.) in Spanish developed and customized for Ingenieros Civiles Asociados (ICA), Mexico City, México; Author and Instructor
- *Effective Management of Small/Special Projects: Strategies, Methods, and Tools*, an educational module (8 hrs.) partially based on published CII Educational Module, developed for The Greater New Orleans Business Roundtable, through the

Department of Civil and Environmental Engineering at the University of New Orleans, New Orleans, Louisiana, 1997; partial Author and Instructor

- *Taller Ejecutivo de Innovación Tecnológica para la Construcción (Executive Workshop on Technological Innovation in Construction)*, a workshop (8 hrs.) in Spanish developed for the Fundación Nacional de la Industria de la Construcción, Mexico City, México; Author and Instructor
- *Herramientas y Tecnicas de Avanzada para el Manejo Efectivo de Proyectos (Advanced Tools and Techniques for Effective Project Management)*, an educational module (8hrs.) in Spanish developed and customized for the Fundación Nacional de la Industria de la Construcción, Mexico City, México; Author and Instructor
- *Constructability*, an educational module (8 hrs.) developed and customized for NASA through the Alliance for Construction Excellence (ACE), Arizona State University, Tempe, Arizona, 1996; Author and Instructor
- *Constructability*, an educational module (8 hrs.) developed and customized for FERMCO through the Construction Industry Cooperative Alliance (CICA), Clemson University, Clemson, South Carolina, 1995; Author
- *Constructability*, an educational module (8 hrs.) developed and customized for Georgia Pacific through the Construction Industry Cooperative Alliance (CICA), Clemson University, Clemson, South Carolina, 1995; Author and Instructor
- *Beyond Technical Competence...*, an educational module (4 hrs.) developed for the Alliance for Construction Excellence (ACE) at Arizona State University, Tempe, AZ; Author and Instructor
- *Using Generic Software to Enhance Construction Project Management Effectiveness*, an educational module (4 hrs.) developed for the Alliance for Construction Excellence (ACE) at Arizona State University, Tempe, AZ; Author and Instructor
- *Constructabilidad y Modularizacion (Constructability and Modularization)*, an educational module (4 hrs.) in Spanish developed for the Fundación Nacional de la Industria de la Construcción, Mexico City, México; Author and Instructor
- *Modularization in Industrial Construction*, based on published CII Educational Module, sponsored by the Construction Owners Association of the Tri-State, Inc.; Cincinnati, Ohio, Invited Instructor
- *Tecnologias Avanzadas de Computacion para la Ingenieria, Administracion, y Gerencia de la Construcción (Advanced Computer Technologies for Construction Engineering and Management)*, an educational module (20 hrs.) in Spanish developed for the Department of Civil Engineering of the University of Los Andes, Continuing Education Short Course Series for Construction Professionals, Bogotá, Colombia; Co-Author and Co-Instructor, with Diego Echeverry
- *Advanced Tools and Techniques for Effective Project Management*, 7 hrs, Officially Approved Course #04PO251-1 and Officially Approved Instructor (#04PO251) by the Construction Industry Licensing Board of the Florida Department of Business and Professional Regulation to provide Continuing Education classes to all contractors licensed by the Board, Atlanta, Georgia, 1994; Author and Instructor
- *Modularization in Industrial Construction*, based on published CII Educational Module, sponsored by the St. Louis Council of Construction Consumers; St. Louis, Missouri; Invited Instructor
- *Implementing Constructability in Utility Companies*, an educational module (8 hrs.) developed and customized for the Electric Power Research Institute (EPRI) and Edison Electric Institute (EEI) through the Construction Industry Institute (CII), The University of Texas at Austin; Austin, Texas, 1994; Co-Author and Co-Instructor, with James T. O'Connor

Contributions

Disciplinary Contributions

[This section explains the ways in which the activities, findings, and products of the program under this award are significant to Construction Engineering and Management, and Civil and Environmental Engineering.]

The research and teaching activities, findings, and products program under this award have directly contributed to expand the knowledge base of the field of Construction Engineering and Management, within the Civil and Environmental Engineering discipline, at both fundamental and applied levels. The comprehensive systems-based framework for increasing the effectiveness and efficiency of F&CIS projects throughout their complete life cycle developed within the program under this award:

- has enabled the establishment of a research and teaching infrastructure that can partner with the A/E/C industry, with public and private owner organizations, with architectural and engineering design organizations, with construction organizations, and with institutions involved in construction research and education (a) to develop and implement new and integral solutions to the problems, satisfaction of the needs, and realization of the opportunities facing them; (b) to enhance the sustainability, performance, quality, and productivity of F&CIS projects; (c) to educate and train better students at the undergraduate, graduate, and professional continuing education levels
- will enable owners, designers, and constructors to proactively, formally, explicitly, and systematically incorporate sustainability principles and concepts into the decision-making process at any phase of the life cycle of a project to reduce or minimize natural resource depletion and degradation, waste generation and accumulation, and environmental impact and degradation caused by current approaches to the delivery and use of F&CIS
- will enable owners, designers, and constructors to proactively, formally, explicitly, and systematically incorporate lean thinking principles and concepts into the technical and management processes at any phase of the life cycle of a F&CIS project (a) to increase in the overall value of the project to the owner; (b) to define better and maintain the flow of the value stream in the execution of a project; (c) to reduce the cycle time of the project; to (d) better manage the construction production process; and (e) eliminate waste
- will enable owners, designers, and constructors to (a) develop and implement an advanced technological infrastructure for enterprise-level and project-level management of knowledge, experience, data, and information; and (b) apply advanced construction materials and equipment technologies in F&CIS projects

Multi- and Interdisciplinary Contributions

[This section explains the ways in which the activities, findings, and products of the program under this award are significant to other fields or disciplines.]

The program under this award has directly contributed to expand the knowledge base of other fields and disciplines. The main reason is that the scope of the program under this award addresses knowledge domains that are intrinsically multi- and interdisciplinary: (a) the A/E/C industry as a general context, (b) F&CIS projects as a specific focus, and (c) sustainability, performance, quality, and productivity as specific goals. In addition, close examination of the activities, findings, and products described previously will reveal the high level of multi- and interdisciplinary collaboration that permeated the research, teaching, and outreach programs. For these efforts, Dr. Vanegas received the 1998 Georgia Tech Outstanding Interdisciplinary Activity Award.

Specific examples of multi- and interdisciplinary collaboration include:

- the advanced computer laboratory for environmentally conscious design and construction involves academic and research faculty from (a) the College of Engineering, specifically from the

Construction Engineering and Management Program in the School of Civil and Environmental Engineering; (b) the College of Architecture, specifically from the Building Construction Program, the Architecture Program, and the City Planning Program, and from the Building Technology and Design Computing Doctoral Programs; and (c) from the Safety, Health, & Environmental Technology Division (SHETD) of the Electro-Optics, Environment, & Materials Laboratory (EOEML) of the Georgia Tech Research Institute (GTRI)

- the development and implementation of a curriculum in sustainable development and technology involved faculty from (a) the College of Engineering, specifically from the schools of Civil and Environmental Engineering, Mechanical Engineering, Chemical Engineering, Industrial and Systems Engineering; (b) the College of Computing; (c) the College of Sciences; and (d) the Ivan Allen College, specifically the School of Public Policy
- the development and implementation of a curriculum in infrastructure assessment, rehabilitation, and reconstruction involved faculty from the School of Civil and Environmental Engineering, specifically from the Construction Engineering and Management Program, the Structural Systems Program, and the Geosystems Program
- the program under this award has contributed to three multi- and interdisciplinary centers at Georgia Tech: (a) the Construction Resource Center (CRC), a joint collaboration between the College of Architecture, specifically from the Building Construction Program, and the College of Engineering, specifically from the Construction Engineering and Management Program in the School of Civil and Environmental Engineering; and (b) the Institute for Sustainable Technology and Development (ISTD), an alliance of research and educational centers addressing industry, manufacturing, and the environment, and more specifically, regional, urban, and campus environmental issues
- many of the organizations around the world with which Dr. Vanegas has developed alliances and partnerships, are inherently multi- and interdisciplinary

Contributions to Human Resources Development

[This section explains the ways in which the activities, findings, and products of the program under this award have contributed to human resource development in science, engineering, and technology.]

As described in previous sections of this report, the research and teaching activities within the program under this award have directly contributed to human resource development in science, engineering, and technology. Specific examples of this contribution include:

- undergraduate, graduate, and doctoral students have been involved as assistants in research and teaching activities
- undergraduate and graduate students have been exposed to new course and curriculum developments, and to enhancements to the teaching and learning processes
- faculty from Georgia Tech and other universities in the U.S. and in other countries have been involved in multi- and interdisciplinary research and teaching activities
- middle and high school teachers from the Atlanta Metropolitan Area received training in research, in the use of educational multimedia technology, and in the application of new pedagogical approaches to the classroom

- practitioners in the A/E/C industry in the U.S. and other countries have been contributors to the development of continuing education programs, courses, and workshops, or participants in them

Dr. Vanegas has a long track record of mentoring and advising the community of Hispanic students within the College of Engineering and within other colleges at Georgia Tech. He currently serves as the Faculty Advisor for the Society of Hispanic Professional Engineers Student Chapter at Georgia Tech, and is in the process of establishing closer links between Georgia Tech and the professional Hispanic and general Hispanic communities in the Southeast. Consequently, from its inception, this program had very explicit goals for ensuring diversity, and reaching out to traditionally under-represented groups. A close examination of research and teaching activities will reveal that a significant portion of the students involved in research and teaching activities have been African-American, Hispanics, and women.

Contributions to the Infrastructure for Research and Education

[This section explains the ways in which the activities, findings, and products of the program under this award have contributed to the general infrastructure for research and education.]

As mentioned previously, the activities and findings of the program under this award provided a foundation for the establishment of an advanced computer laboratory for environmentally conscious design and construction, with funding support from the Georgia Research Alliance. This laboratory provides design, visualization, modeling, prototyping, simulation, multimedia, and other computational capabilities and functionalities that enable collaborative based research activities among members of a multidisciplinary team, utilizing shared video. It also supports research and development of strategies, methodologies and tools/techniques for environmentally conscious design and construction of F&CIS projects, and for environmentally conscious building technologies, systems, products and materials.

The activities and findings of the program under this award also provided a foundation for the establishment of a focused, multi-disciplinary, and self-sustaining institutional infrastructure for affordable sustainable housing education, research, and outreach for the U.S. and the Americas, with funding support the Fred and Teresa Estrada Young Professor in the College of Engineering.

Public Welfare Contributions

[This section explains the ways in which the activities, findings, and products of the program under this award have contributed to the public welfare beyond science and engineering.]

Our modern society has developed an undisputed dependence F&CIS. For any nation, the quality of life of its citizens and communities, and the effectiveness of its organizations in the public and private sectors, are inextricably related to the performance and sustainability of the built facilities that house them, and the civil infrastructure systems that serve them (i.e., water, transportation, waste, energy, and communications). These systems provide the foundation and lifelines that enable a society to function, grow, and ultimately, survive. Consequently, any improvements to the sustainability, performance, quality, and productivity of the A/E/C industry in general, and to F&CIS projects specifically, will inevitable benefit society at large. The activities, findings, and products of the program under this award provide a solid foundation toward this goal.

People, Partner Organizations, and Other Collaborators

Information on People

[This section lists people who have contributed to the research and teaching activities within the program under this award.]

Previous sections of this report have listed the various people who have contributed to the research and teaching activities within the program under this award.

Information on Partner Organizations

[This section lists organizations, within the U.S. and abroad, which have contributed to the research and teaching activities within the program under this award.]

Previous sections of this report have listed partner organizations outside Georgia Tech, within the U.S. and abroad, which have been involved with the project, and that have provided financial or in-kind support, supplied facilities or equipment, collaborated in the research, exchanged personnel, or otherwise contributed to the research and education program.

Information on Other Collaborators

[This section lists other significant collaborators or contacts within and outside Georgia Tech who have contributed to the research and teaching activities under this award.]

Previous sections of this report have listed other significant collaborators or contacts within and outside Georgia Tech, who have contributed to the research and teaching activities within the program under this award.

Appendix A:

Other Related Sponsored Projects

Sponsored Projects Related Directly and Indirectly to the Research Program under this Award

<u>Project Start/Duration</u>	<u>Sponsor</u>	<u>Topic</u>	<u>Involvement</u>
January 1999 (6 months)	Clark Atlanta University <u>Amount:</u> \$35,000 Special subcontract	<i>Technology-based Economic Development for the 5th District of the State of Georgia</i>	Proposal Co-Author and Project Co-PI (with Kangari)
January 1999 (6 months)	Georgia Tech Foundation <u>Amount:</u> \$28,542 (special sabbatical leave) plus \$35,000 in matching funds from Winter Construction Company	<i>Environmentally Conscious Design and Construction of Facilities and Civil Infrastructure Systems</i>	Proposal Author and Project PI
April 1997 (6 months)	National Science Foundation - CONACyT Collaborative Research Opportunities (CRO) Program <u>Amount:</u> \$10,000 (supplement to existing NSF-NYI award)	<i>Environmentally Conscious Design and Construction of Affordable Housing</i>	Proposal Author and Project PI
April 1997 (1 year)	Georgia Research Alliance - Equipment Grant <u>Amount:</u> \$229,100	<i>Advanced Computer Laboratory for Environmentally Conscious Design and Construction Research Initiative</i>	Proposal Author and Project PI
January 1995 (3 years)	Construction Industry Institute <u>Amount:</u> \$135,000	<i>Innovative Practices for Cost Effective Projects</i>	Proposal Author and Project PI
January 1993 (1 year)	Joint Highway Research Project (JHRP)-Indiana Department of Transportation/Purdue <u>Amount:</u> \$50,000	<i>An INDOT Constructability Program and Constructability Lessons Learned Integrated Multimedia System</i>	Proposal Co-Author and Research Associate (with McCullough)

Sponsored Projects Related Directly and Indirectly to the Teaching Program under this Award

<u>Project Start/Duration</u>	<u>Sponsor</u>	<u>Topic</u>	<u>Involvement</u>
January 2000 (1 month)	U.S. Steel Gary Works – No. 1 Caster EMC Replacement Project <u>Amount:</u> \$8,000 (through Continuing Education – College of Engineering)	<i>Development and Delivery of a Project Alignment and Partnering Development Seminar</i>	Proposal Author and Project PI
January 2000 (1 month)	U.S. Steel Gary Works – No. 2 QBOP Tuyere Cooling-Propane Project <u>Amount:</u> \$8,000 (through Continuing Education – College of Engineering)	<i>Development and Delivery of a Project Alignment and Partnering Development Seminar</i>	Proposal Author and Project PI

Sponsored Projects Related Directly and Indirectly to the Teaching Program under this Award
(continued)

<u>Project Start/Duration</u>	<u>Sponsor</u>	<u>Topic</u>	<u>Involvement</u>
November 1999 (1 month)	Associação das Empresas do Mercado Imobiliário de Pernambuco <u>Amount:</u> \$7,000 (through Continuing Education – College of Engineering)	<i>Development and Delivery of a Special Course/Technical Visit on Strategies, Methods, and Tools for Effective Management of Residential Construction Enterprises & Projects</i>	Proposal Author and Project PI
July 1999 (1 month)	U.S. Steel Gary Works – BH Upgrade Project <u>Amount:</u> \$10,000 (through Continuing Education – College of Engineering)	<i>Development and Delivery of a Project Alignment and Partnering Development Seminar</i>	Proposal Author and Project PI
April 1999 (1 month)	U.S. Steel Gary Works – 20/20 Projects: Sub-lance, Oxygen Lance, Auxiliaries, and Charge Weigh <u>Amount:</u> \$10,000 (through Continuing Education – College of Engineering)	<i>Development and Delivery of a Project Alignment and Partnering Development Seminar</i>	Proposal Author and Project PI
January 1999 (2 months)	U.S. Steel Gary Works – New Hydraulic Coilers Project <u>Amount:</u> \$12,000 (through Continuing Education – College of Engineering)	<i>Development and Delivery of a Project Alignment and Partnering Maintenance Seminar</i>	Proposal Author and Project PI
October 1998 (3 years)	GE Fund <u>Amount:</u> \$300,000	<i>Faculty for the Future Program</i>	Project Co-PI (with Wepfer, May, Baker)
May 1998 (2 months)	U.S. Steel Gary Works – New Hydraulic Coilers Project <u>Amount:</u> \$16,000 (through Continuing Education – College of Engineering)	<i>Development and Delivery of a Project Alignment and Partnering Development Seminar</i>	Proposal Author and Project PI
February 1998 (2 months)	Siemens Energy & Automation, Inc. <u>Amount:</u> \$17,700 (through Continuing Education – College of Engineering)	<i>Development and Delivery of a Course on Advanced Strategies, Techniques, and Tools for Effective Project Management (in Spanish)</i>	Proposal Author and Project PI
April 1997 (6 months)	National Science Foundation - Research Experiences for Undergraduates (REU) Program <u>Amount:</u> \$10,000 (supplement to existing NSF-NYI award)	<i>Environmentally Conscious Design and Construction Research Initiative</i>	Proposal Author and Project PI
April 1995 (6 months)	EduTech at Georgia Tech <u>Amount:</u> \$10,515 plus \$12,650 in matching funds	<i>An Integrated Case-Based Environment for Design</i>	Project Co-PI (with Chinowsky, Lonnman)